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Effect of Compacting Pressure on Fuel Properties of Finger Millet Briquettes

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Abstract
In this work, the effect of compacting pressure on fuel properties of finger millet briquettes was investigated and reported. Four different varieties of finger millet namely P224, Gulu-E, U-15 and Okhale-1 were used to produce briquettes without a binder using manual hydraulic press at predetermined compacting pressure of 15, 25 and 35MPa. The proximate analysis results of the resultant briquettes was between 68-70% volatile matter, 21-24% fixed carbon, 9-11% moisture content and 7-8% ash content which is comparable with those of other biomass materials such as rice, wheat and wood. On the effect of compacting pressure on fuel properties, the study showed an increasing trend in briquette density and compressive strength as compacting pressure increased from 15 to 35MPa. However, as compacting pressure increased, the burning rate decreased due to reduced air voids in the briquettes thus limiting mass and heat transfer during combustion.
Keywords: Burning rate, Briquettes, Compacting Pressure, Density, Finger Millet straws

1. Introduction

The rapid depletion of fossil energy sources as a result of population growth has shifted the attention to alternative sources of energy that are renewable, sustainable, CO_2 neutral and environmental friendly due to reduced greenhouse gas (GHG) emissions. Out of the various renewable energy sources, biomass presents the most promising option due to its enormous availability. For instance, agricultural residuals accounts for approximately 140 billion metric tonnes of biomass per year in the world from different agricultural crops such as maize, wheat, millet, sugarcane, rice coffee, cassava, sorghum and barley. Huge quantities of energy can be generated from this volume of biomass (Jekayinfa and Scholz, 2009). Kenya generates about 14 million metric tonnes of agricultural residue from various agricultural crops such as maize, rice, coffee, millet, etc. every year with an equivalent energy potential of 187.4 GJ. The annual finger millet residue estimates in Kenya is about 112,000 metric tonne with a corresponding energy potential of 1.4 million GJ (Kimutai et al., 2014). However, due to lack of proper management, these residues are burned directly in the field resulting in air pollution and disruption of natural biochemical composition of the soil. In some part of Kenya, major proportion of crop residues such as maize stalk and sugarcane bagasse is used as a source of domestic energy in direct burning with lower thermal efficiency and associated pollution challenges. In some cases these wastes are left unattended in agricultural fields resulting into visual obstruction, environmental degradation and land pollution due to accumulation. Generally, agricultural residues are characterized with low density (60-180 kgm^{-3}) causing management challenges in terms of transportation, storage and mechanical handling thus hindering the conversion of these wastes to solid fuels for domestic purpose (Bhattacharya et al., 1989) thus the need for improved technologies such as briquetting. Briquetting technology improves the physical strength, enhances the volumetric calorific value and reduces the volume thus increasing the density of agricultural wastes (Wakchaure and Indra, 2009). The use of briquetting technology for finger millet straws (residues) will provide renewable energy source for domestic applications to replace firewood and charcoal which are domestic energy sources commonly used in many rural and urban households. This will save the country from deforestation as well as air and land pollution in addition to realizing the national energy policy in terms of environmental and economic impact, and energy demands of a country (Thabuot et al., 2015). For this work, four varieties of finger millet were used in preparing the briquettes without a binder using a manual hydraulic press followed by determination of the fuel properties of the resultant solid fuel. Since compacting pressure plays a crucial role during briquetting process, the study further investigated the effect of compacting on fuel properties of the briquettes.

2. Methodology

Four varieties of finger millets namely P-224, Gulu-E, Okhale-1 and U-15 used in this research were obtained from Kenya Agricultural Research and Livestock Organization (KARLO), Kakamega station. Finger millet straws were dried in the sun for four day to reduce the moisture content and then subjected to milling process in an electric hammer mill with circular sieve openings. To avoid species contamination, the hammer mill was thoroughly cleansed before loading another species. This was followed by sieving process whereby milled finger millet straws were subjected to 1.18mm sieve size. For briquetting process, 42grams of each variety was weighed and filled into a cylindrical mould measuring 5.53cm internal diameter and 5.25cm height. The briquettes were formed through manual hydraulic press of biomass material in the mould cavity at 15, 25 and 35MPa compacting pressure with a constant dwelling time of 60 seconds. The resultant briquettes were stored at ambient condition before analyzing different fuel properties. Experimental procedure ias summarized in Fig. 1 below.

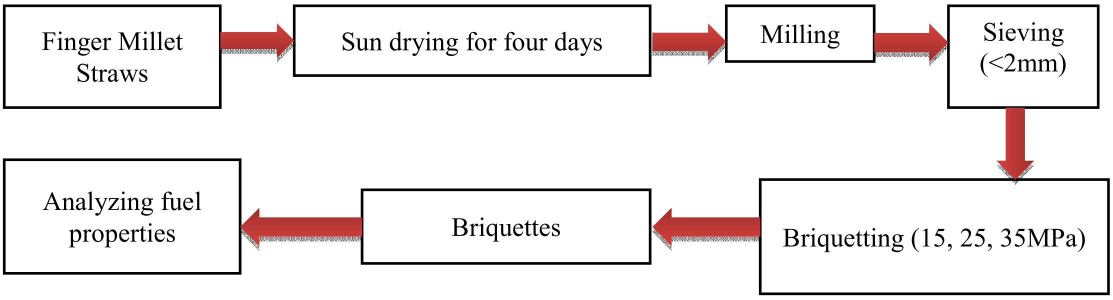

Figure 1: Experimental Procedure

Analysis of the fuel properties involved the determination of fixed carbon, volatile matter, ash content and moisture content. The volatile matter was performed using dry sample in a heating furnace at a temperature of 350^{0}C for 20 minutes in accordance with ASTM E872-82. Ash content was determined in a furnace at 550^{0}C for three hours followed by cooling and weighing according to ASTM D2166-85. The quantity of fixed carbon was determined from weight difference. Moisture content was determined on oven-dry basis as per ASTM D4442-15 standards. The calorific/heating value of the briquettes was determined using ballistic bomb calorimeter. Briquette density was calculated by dividing mass by the volume of the briquettes while the compressive strength of the briquettes was determined based on ASTM D2166-85 on Instron universal strength testing machine. The burning rate of the briquettes was determined as highlighted by Musa (2007). This involved igniting oven-dried samples over a Bunsen burner till the fire extinguished and recording burning rate in grams per minute.

3. Results and Discussions

Proximate analysis of fuel include determination of moisture content, volatile content, fixed carbon and ash content. Fixed carbon and volatile matter represent the amount of carbon and organic substance present in the fuel material, respectively. Normally, agricultural wastes with higher volatile matter has lower fixed carbon content and is characterized by ease ignition with smoky flame because volatile matter comprises combustible gases as well as hydrocarbons (Pandey and Dhakal, 2013). Of the four varieties of finger millet straws studied, P224 showed the highest percentage of volatile matter of 70.79% followed by Okhale-1, Gulu-E and U-15 respectively at 70.72, 68.72 and 68.51%. For fixed carbon, U–15 showed high fixed carbon of 24.31% while P224 had the lowest of 21.38% (see Table 1). The amount of fixed carbon is a measure of the calorific heating value of biomass. Finger millet straws showed a low content of fixed carbon. This is a common characteristic for biomass thus making it uneconomical for the production of carbonised briquettes, but favours more of gasification (Omwando, 2006). Ash content of biomass indicates sluggish behavior during combustion i.e. lower ash content indicates lower sluggish behavior. In the study, Gulu-E had a high ash content of 8.38% while Okhale-11 and U-15 have a low ash content of 7.18%. The moisture content of the briquettes varied between a minimum of 9.51% for Okhale-1 and U-15; and a maximum of 11.02% for P224 which was within the acceptable operating moisture content range of 8-12% required for briquette making (Eriksson and Prior, 1990). Moisture content of biomass influences particle heating by increasing the energy required for heating and drying. This results in delayed release of volatiles in addition to affecting the combustion rates of the fuel (Werther et al., 2000).

Table 1: Proximate analysis (dry basis) of finger millet straws

Species	Volatile Matter (%)	Fixed Carbon (%)	Ash Content (%)	Moisture Content (%)
Okhale–1	70.72	22.10	7.18	9.51
Gulu – E	68.72	22.91	8.38	10.73
U – 15	68.51	24.31	7.18	9.51
P224	70.79	21.38	7.87	11.02

To study the effect of compacting pressure on briquette compressive strength, briquettes produced using different predetermined compacting pressures were placed vertically on a horizontal metal plate of the machine. Briquettes produced from finger millet straws showed increasing compressive strength with increasing compacting pressure. For instance, P224 variety showed minimum compressive strength of between 7.6 and 11.1N/mm^2 whereas Gulu-E variety showed a maximum compressive strength of between 20.1 and 29.6N/mm^2 as compacting pressure increased from 15 to 35MPa (see Fig. 2).

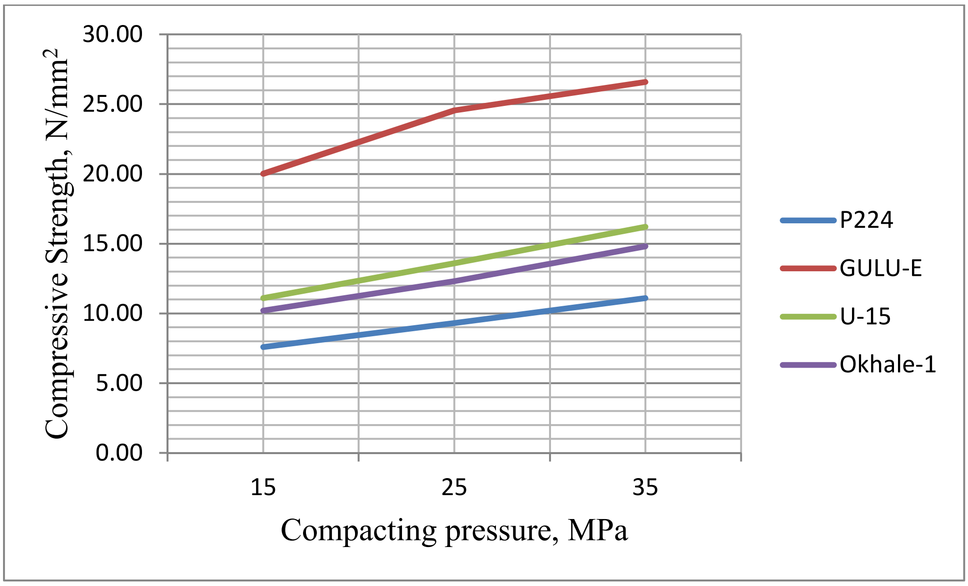

Figure 2: Effect of Compacting pressure on briquette compressive strength

The density of the briquettes increased with increase in compacting pressure (see Fig. 3). Briquettes prepared from Okhale-1 were denser while those prepared from Gulu-E were most loose.

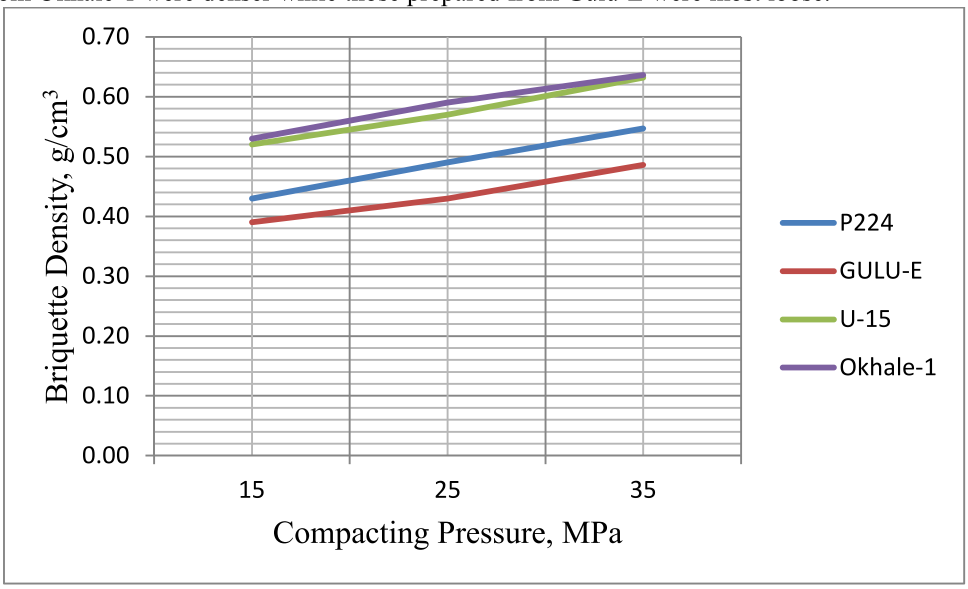

Figure 3: Effect of compacting pressure on briquette density

For instance, as compacting pressure increased from 15MPa to 35MPa, the density of Okhale-1 increased from 0.53g/cm^3 to 0.636g/cm^3 while the density of Gulu-E increased from 0.39g/cm^3 to 0.486g/cm^3. An increasing trend in briquette density with compacting pressure reported in this study is congruent with other studies on fuel properties of biomass (Unpinit et al., 2015 and Saeidy, 2004) and can be explained that Okhale-1 required lower compression energy to fill the inter-particle spaces. The increase in briquette density with compacting pressure increases both the volumetric energy density and bulky density thus making briquette handling, transportation and storage easier (Theerarattananoon et al., 2011).

Fig. 4 shows the variation of burning rate of briquettes with compacting pressures. After ignition, the size of the briquette reduced progressively as burning continued.

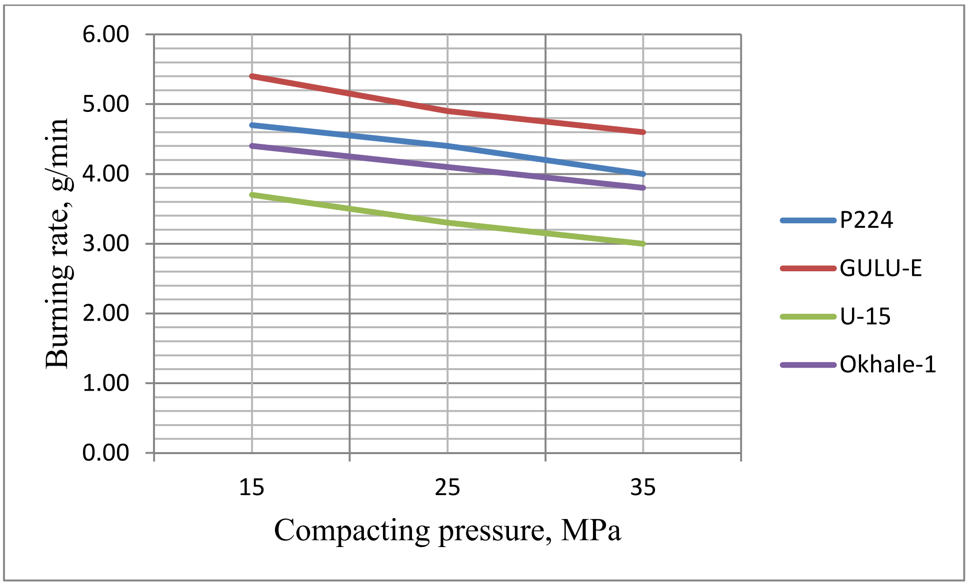

Figure 4: Effect of compacting pressure on briquette burning rate

From Fig. 4, it can be deduced that burning rate of the briquettes decreased with increasing in compacting pressure. Similar trend of reducing burning rate with increase in compacting pressure has been reported in literature (Ghorpade and Moule, 2006) and this can be explained that as the compacting pressure increases during briquette production, low porosity briquettes with reduced air voids are produced. The low porosity briquettes tend to limit mass and heat transfer during combustion. This implies that briquettes produced at low compacting pressure have air voids hence higher high porosity and higher burning rate. From the results, the minimum burning rate reduced from 3.7g/min to 3.0g/min for U-15 whereas the maximum burning rate reduced from 5.4g/min to 4.6g/min for Gulu-E as compacting pressure increased from 15MPa to 35MPa. Therefore, there exists an indirect relationship between burning rate (g/min) and briquette density (g/cm^3) of biomass since Gulu-E showed lowest density and highest burning rate of the four finger millet varieties under study.

Conclusion

The rapid depletion of petroleum energy sources has shifted the attention into renewable sources of energy for domestic and industrial application. Biomass provides an alternative source of energy due to their renewability, availability and naturally sustainable. However, biomass in their natural state is difficulty to handle, transport and store, hence, the need for briquetting technology to enhance handling, transportation and storage of biomass energy sources. In this study, fuel properties of the briquettes such as compressive strength and density increased with compacting pressure while burning rate of the briquettes reduced as compacting pressure increased from 15MPa to 35MPa. On the other hand proximate analysis results of briquettes produced from finger millet straws was comparable with other biomass such as wheat, wood and rice which are commonly used sources of energy sources.

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